MAX-PLANCK-GESELLSCHAFT

MPI FÜR BIOLOGICAL CYBERNETICS

Teleporting works – Spatial updating experiments in Virtual Tübingen

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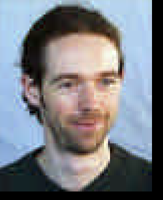
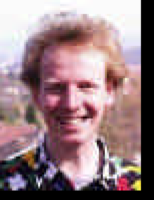




Red Thread

Challenge:

Disorientation in virtual environments and multimedia spaces

– both annoying and interesting

Ultimate Goal:

1. Understanding (spatial cognition):

   What is essential for quick & intuitive spatial orientation?

   → automatic spatial updating!

   → But how can we achieve this?

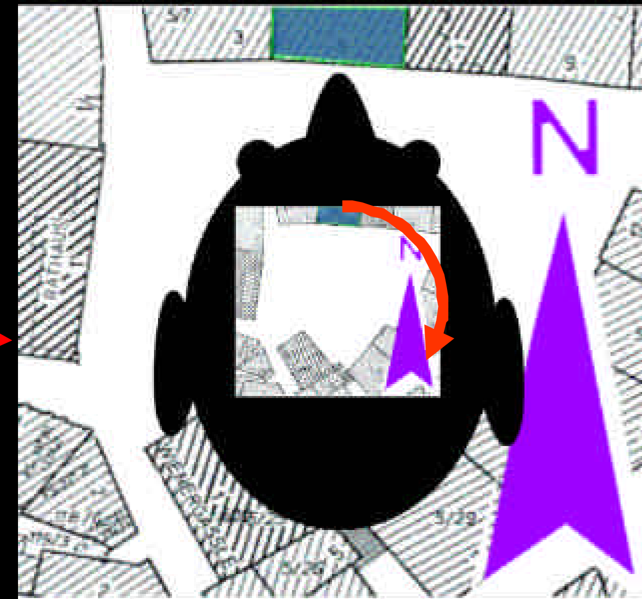
2. Implementing (human factors):

   Lean approach – how to cheat intelligently?

“Automatic” vs. “Obligatory” Spatial Updating

generalized spatial updating

= transformation of egocentric mental
spatial reference frame, e.g.,
during imagined ego-motions or perspective-taking



(automatic) spatial updating

automatized, quick, intuitive,
low cognitive load,
does not require (much) attention,
--> spatial cues CAN be used for spatial updating

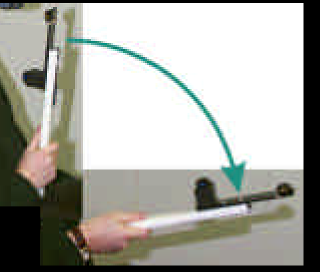
obligatory spatial updating

reflex-like, hard-to-suppress,
cognitively mostly impenetrable,
--> spatial cues MUST be used for spatial updating

Background

- Previous findings:
  - Behavioral measure: Rapid pointing
  - Real world = VR if FOV the same.
  - Photorealistic visual cues alone *can* be sufficient.
  - Vestibular cues not as essential as commonly believed. (They can, however, partially compensate insufficient visual cues.)
  - Small FOVs impair spatial updating.
  - Optic flow does influence mental reference frame, but is nevertheless insufficient for good spatial updating.

  (Riecke et al, VSS 2001 & 2002, TWK 2001 & 2002, & dgps 2002)



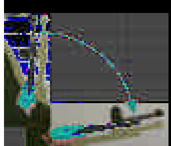
- Open Questions:
  - Influence of turning angle
  - Are continuous motions required? I.e., does teleporting work in VR?

Methods – Virtual Scenery

Targets: 22 landmarks

Methods - Setup

- Vestibular stimuli: 6 dof Motion Platform
- Visual stimuli: LCD video projection setup
  - – 86° x 64° FOV
- Task: Rapid pointing after consecutive rotations
  1. Auditory announcement of next trial
  2. Motion phase (turn) 
  3. Pointing phase:
     - Auditory target announcement
     - Subsequent speeded pointing to targets outside of the current FOV: Point “as accurately and quickly as possible!”
     - Raising pointer to upright (default) position
     - Repeat 4 times



Methods – Experimental Design

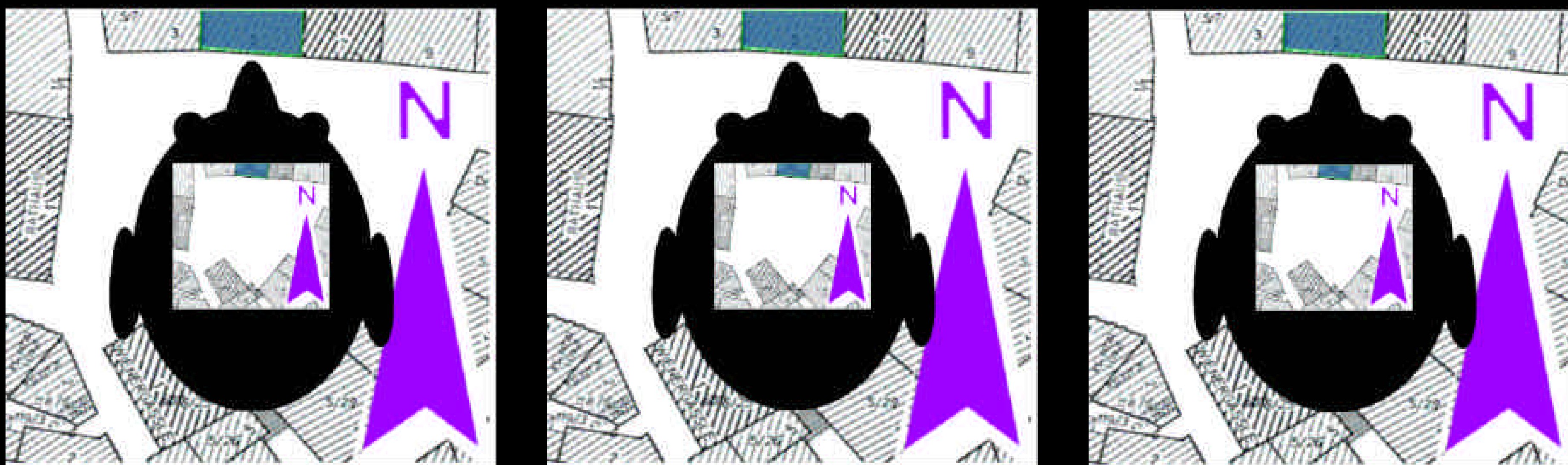
- N=8 highly trained participants (follow-up exp.)
- 3 spatial updating conditions were alternated

CONTROL (baseline for "optimal" performance)

UPDATE (*can* spatial cues be used for spatial updating?)

IGNORE (*must* spatial cues be used for spatial updating?)

→ test *reflex-like* character



UPDATE = CONTROL

↔ ***automatic* spatial updating**

IGNORE >> UPDATE

↔ ***obligatory*, reflex-like spatial updating**

Methods – Experimental Design

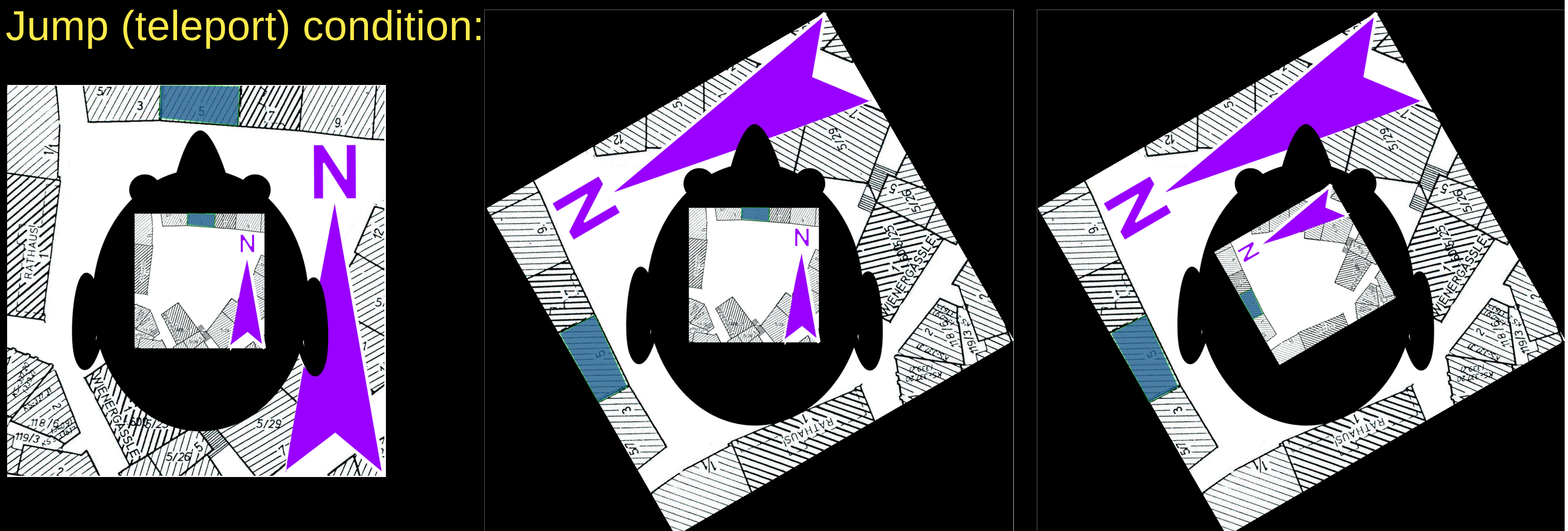
- 3 stimulus combinations:

Block	Orientation (yaw) range	Physical motions	Smooth visual motions	Mean visual turn velocity
A	[-57°, 57°]	Yes	Yes	20°/s
B	[-228°, 228°]	Yes	Yes	80°/s
C	[-228°, 228°]	No	No (jump)	jump

A vs. B: Turning angle (same movement durations)

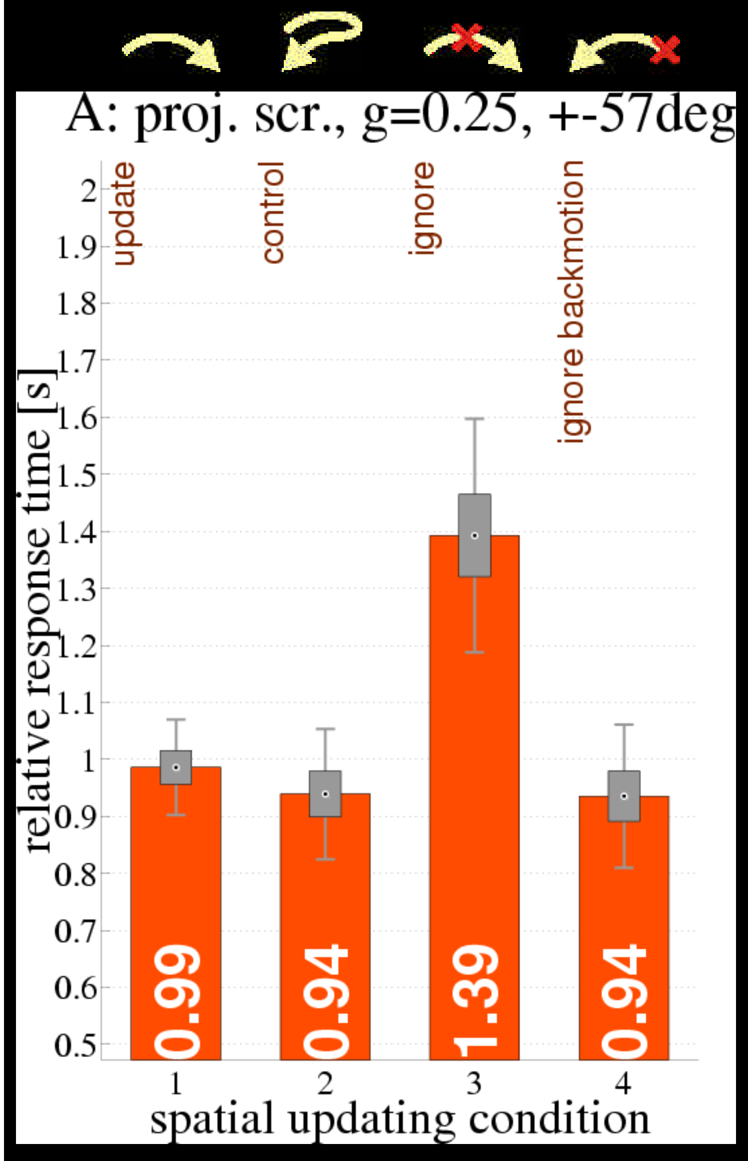
B vs. C: Continuous vs. jump motion (same turning angles)

- Jump (teleport) condition:



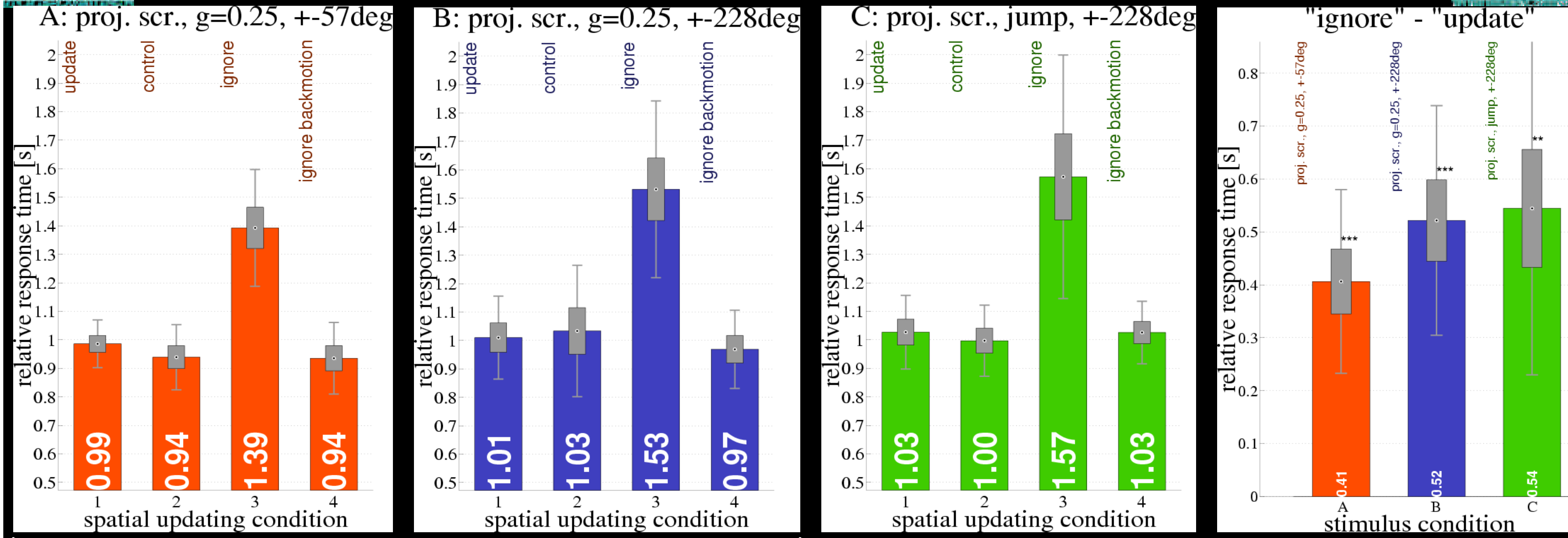
Results – Block A (small turning angles), RT

Response time: How intuitive (fast) is the access to our spatial knowledge?



- UPDATE: Quick responses, compared to literature (1.6-12s). → Ease and intuitive usability of our pointing metaphor.
  - Pointing after blindfolded rotations: 1.6s (May, 2000),1.7s (Farrell & Robertson, 1998), 1.8-3.2s Rieser (1989) >3s (Creem & Proffitt, 2000; Presson & Montello, 1994).
  - Physical rotations in VR using HMD: 8 - 12s (Wraga et al., under review)
- UPDATE = CONTROL → ***automatic* spatial updating**
- IGNORE >> UPDATE → ***obligatory*, reflex-like spatial updating**
- → Typical response pattern as in literature for obligatory spatial updating

Results – Response times



A vs. B:

- Larger turning angles decreased performance only insignificantly

B vs. C:

- The lack of any motion cues (teleport) did not impair CONTROL or UPDATE performance at all.
- Furthermore, jumps to new orientations were as hard to IGNORE as the smooth, continuous turns to new orientations.

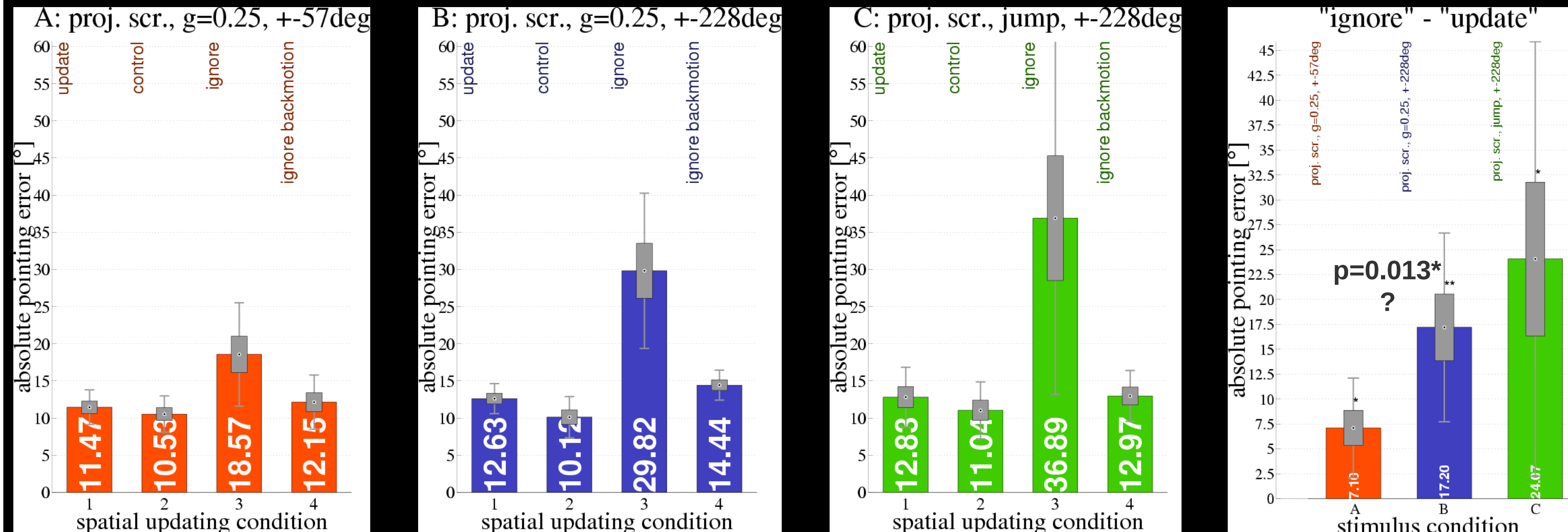
Conclusion:

Automatic and obligatory spatial updating even in teleport condition

(i.e., CONTROL = UPDATE << IGNORE)

Results – Absolute Pointing Error

Absolute pointing error:
How accurately do we know where we are with respect to specific objects of interest?



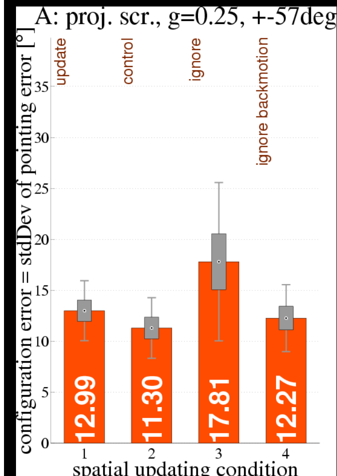
A vs. B:

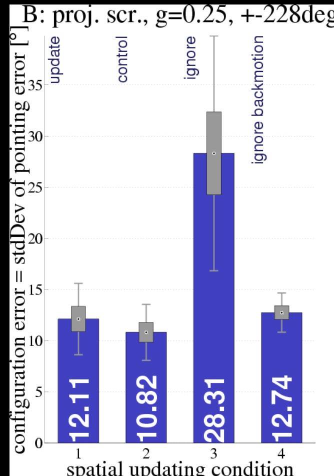
Larger turning angles are harder to ignore

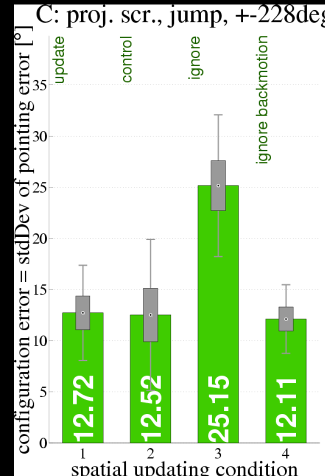
B vs. C:

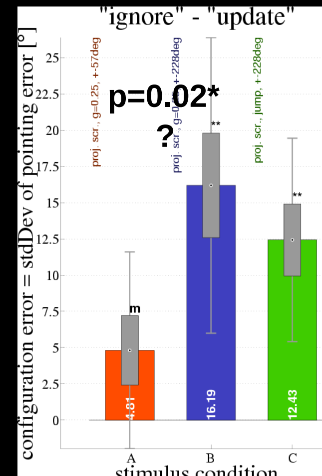
Virtually no difference

Configuration error = Pointing variability: Are the angles between landmarks reported consistently?

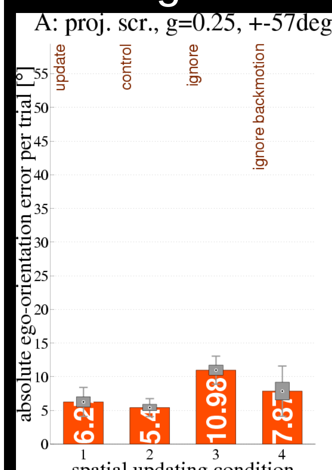


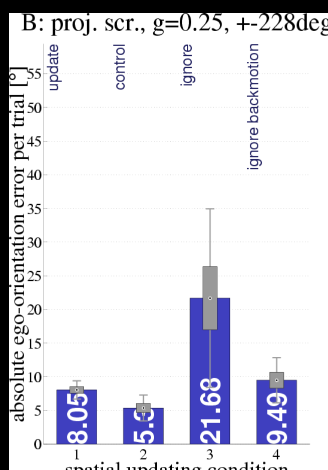


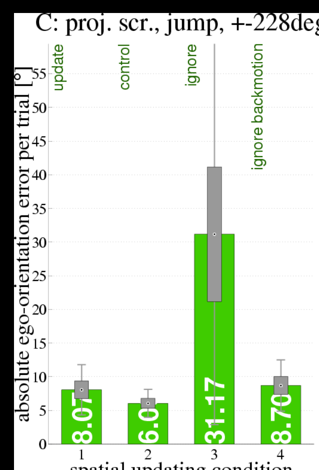


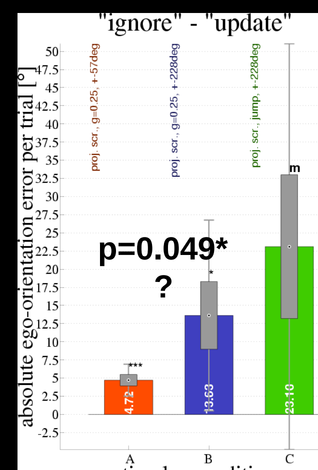


Absolute ego-orientation error per trial: Did participants misperceive their ego-orientation?









Automatic & obligatory spatial updating

A vs. B:

Larger turns are harder to ignore

→ more powerful in initiating obligatory spatial updating

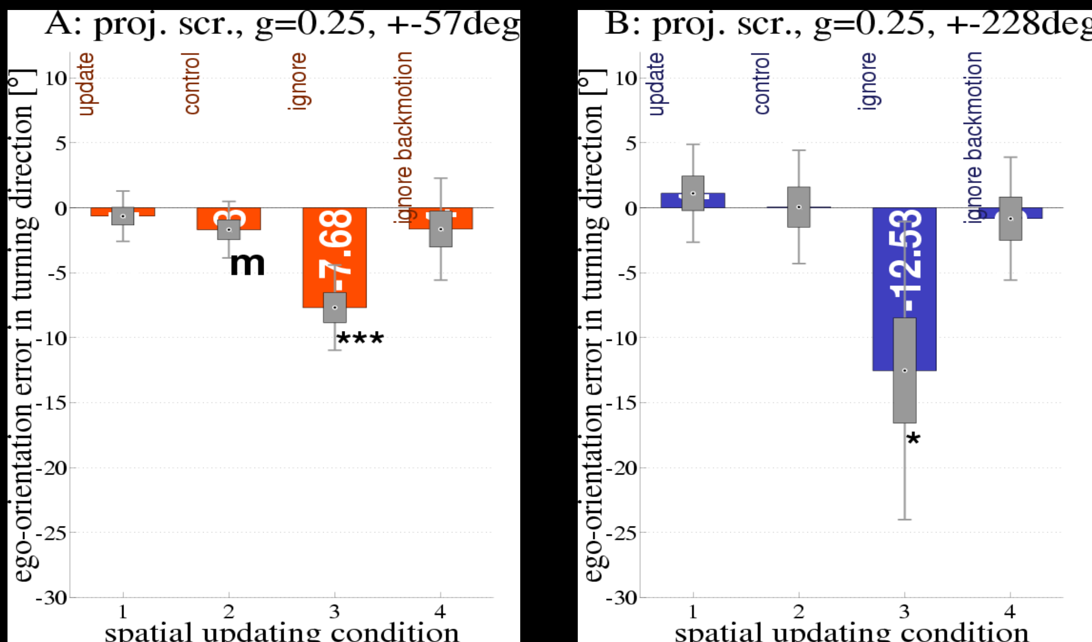
→ increased disorientation

B vs. C:

As before: No clear difference between continuous (B) and jump (C) motion

Results – No Motion Effect at all?

Ego-orientation error in turning direction:
Did participants misperceive their ego-orientation typically in the direction of motion?
→ motion after effect or representational momentum effect?



- No direction-specific error (motion after-effect) for UPDATE & CONTROL condition.
- Clear directional error only for IGNORE trials, but *against* turning direction.
  - Participants were apparently unable to correctly remember their previous orientation and act appropriately.

Summary

Did we really measure spatial updating or just ~~unspecific spatial memory?~~

- IGNORE performance depended on turning angle and motion direction

Turning angles: Larger turns were

- virtually as easy to update as small turns, but
- harder to ignore and hence more powerful in initiating obligatory, reflex-like spatial updating

Continuous vs. jump motion (visual teleport):

- Classical **continuous spatial updating** not sufficient to explain results
- We propose a second mechanism: **“instantaneous spatial updating”**

  (von der Heyde & Riecke, 2002)

  – This discontinuous, jump-like "instantaneous spatial updating" allowed participants to quickly adopt new orientations *without* any explicit motion cues.

  – This teleporting was unexpectedly sufficient in triggering obligatory, reflex-like spatial updating.

- → Neither vestibular cues nor motion cues seem to be absolutely required for proper updating of ego-turns.

Take Home Message

- VR allowed us to disentangle spatial updating into two separate processes:

Continuous Spatial Updating

Instantaneous Spatial Updating

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Abstract

Short abstract

Spatial updating was investigated using rapid pointing to previously-learned targets in high-end Virtual Reality. A photo-realistic virtual replica of the Tübingen marketplace and a motion platform were used for visual and vestibular simulation, respectively. Apart form the smooth spatial updating induced by continuous movement information, we unexpectedly also found discontinuous, jump-like "instantaneous spatial updating" that allowed participants to quickly adopt a new orientation without any explicit motion cues. These slide-show type presentations of new orientations were even sufficient in triggering obligatory, reflex-like spatial updating. This challenges the prevailing opinion that vestibular cues are required for automatic updating of ego-turns.

Long abstract:

INTRODUCTION:

When moving through space, our sensory inputs somehow automatically transform the "world inside our head" accordingly so as to stay in alignment with the outside world. This "spatial updating" of our ego-centric mental spatial representation occurs without conscious effort and is normally "obligatory" in the sense of being mostly cognitively impenetrable and hard to suppress. From the literature, we know that spatial updating is typically impaired when proprioceptive and vestibular cues in particular are missing (Klatzky, Loomis, Beall, Chance, and Golledge, 1998; May & Klatzky, 2000; Presson & Montello, 1994; Rieser, 1989; Simons & Wang, 1998; Wang & Simons, 1999; Wang & Spelke, 2000; Wraga, Creem, & Proffitt, (under revision)). Klatzky et al. (1998) and May & Klatzky (2000) for example found that participants completely forgot to update ego-rotations that were not physically performed, i.e., when the corresponding vestibular and proprioceptive cues were missing. In this experiment, we investigated visual spatial updating with and without concurrent vestibular cues and provide evidence challenging the prevailing opinion that vestibular and proprioceptive cues are absolutely necessary for spatial updating.

METHODS:

A photo-realistic virtual replica of the Tübingen marketplace was presented via a curved projection screen (84°x63° FOV). A Stewart motion platform was used for vestibular simulation. Participants were rotated successively to randomized orientations and asked to point "as accurately and quickly as possible" to four targets randomly selected from a set of 22 salient landmarks that were previously learned. Targets were announced consecutively via headphones and selected to be outside of the current field of view (i.e., between 42° and 110° left or right from straight ahead). Each of the eight participants completed three blocks of different stimulus combinations (blocks A-C, 20 min. each). The visual orientation range was ±57° for block A and ±228° for block B and C. Block C was a "jump" condition, where new views were immediately presented without any continuous visual motion in between. Block A and B included vestibular (physical) motions, block C did not. Within each block, three different spatial updating conditions were used:
UPDATE: Participants were simply rotated to a different orientation. If the available spatial updating cues are sufficient, UPDATE performance should not depend on the angle turned. CONTROL: Participants were rotated to a new orientation and immediately back to the original orientation before being asked to point. This was a simple baseline condition yielding optimal performance: If the available spatial updating cues are sufficient, UPDATE performance should be almost as good as CONTROL performance (äutomatic spatial updating").

IGNORE: Participants were rotated to a different orientation, but asked beforehand to ignore that rotation and "point as if you had not turned". If the available cues are sufficient for triggering spatial updating and hence turn the world inside our head even against our conscious will, those turns should be considerably harder to IGNORE than to UPDATE. Spatial updating would then be "obligatory" in the sense of hard-to-suppress and cognitively almost impenetrable. Performance was quantified in terms of four dependent variables, revealing different aspects of spatial updating:

(1) Response time: How intuitive (fast) is the access to our spatial knowledge?

(2) Configuration error = Pointing variability: Are the angles between landmarks reported consistently?

(3) Absolute pointing error: How accurately do we know where we are with respect to specific objects of interest?

(4) Absolute ego-orientation error per trial: Did participants misperceive their ego-orientation?

RESULTS AND DISCUSSION:

In block A, performance and especially response times varied considerably between participants, but showed the same typical response pattern for obligatory spatial updating in all four dependent variables: UPDATE performance was almost as good as CONTROL performance, whereas IGNORE performance was considerably worse. This indicates excellent automatic as well as obligatory spatial updating. Compared to the literature, where UPDATE response times of 1.6 seconds up to more than 7s are typical, we observed mean response times of only 1.0s, demonstrating the potential of our rapid pointing method. Increasing the visual orientation range from ±57° to ±228° in block B left CONTROL performance unchanged, and decreased UPDATE performance only minimally: The absolute pointing errors increased from 11.4° to 12.6° ($t(7)=3.03$, $p=0.019$*), all other performance measures were virtually the same and did not differ significantly. IGNORE performance, however, was clearly impaired by the increased turning angles in terms of configuration error, absolute pointing error, as well as absolute ego-orientation error ($t(7)=3.01$, $p=0.02$*; $t(7)=3.29$, $p=0.013$*; and $t(7)=2.38$, $p=0.049$*, respectively). This indicates that larger turns are harder to ignore and hence more powerful in initiating obligatory spatial updating.

In block C, participants were presented with new views without any visual or vestibular motion in between ("jump" or "teleport" condition). Unexpectedly, the lack of any motion cues did not impair CONTROL or UPDATE performance at all, compared to block B. Furthermore, jumps to new orientations were as hard to IGNORE as the smooth, continuous turns to new orientations in block B. There was even a slight but insignificant tendency towards larger values for both absolute pointing error and absolute ego-orientation error (increase from 29.8° to 36.9° and 21.7° to 31.2°, respectively). Consequently, merely displaying an image of a new orientation without continuous motion in between can induce obligatory spatial updating. Hence, visual landmark information proved sufficient to instantly trigger a spatial reference frame from a new orientation.

CONCLUSIONS:

Apart form the well-known smooth spatial updating induced by continuous movement information, we found also a discontinuous, jump-like "instantaneous spatial updating" that allowed participants to quickly adopt a new orientation without any explicit motion cues. These slide-show type presentations of new orientations were even sufficient in triggering obligatory, reflex-like spatial updating. This finding was totally unexpected and is to our knowledge unprecedented in the literature. Furthermore, this result conflicts with the prevailing opinion that vestibular cues are required for proper updating of ego-turns. Several factors might explain this difference, primarily the immersiveness of our visualization setup and the abundance of natural landmarks in a well-known, consistent environment.

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